A Rapid, Low-Cost Method for Determination of Soil Bulk Density[1]

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ABSTRACT

Proper characterization of soil bulk density is essential for an accurate interpretation of chemical and microbiological parameters in the field. Reluctance to report soil analyses on a volumetric basis is usually related to requirements of additional time and specialized equipment for determination of soil bulk density. We developed a rapid method utilizing a low-cost hand sampler (< $125) for determination of soil bulk density over several intervals to a depth of 300 mm. The method appears accurate, using five cores per experimental unit, and enables collection of up to ten profiles in the same time required for taking one profile by the Uhland sampling techniques. The method is very precise and coefficients of variation over a range of tillage-management practices, which include inherent soil variability, averaged below 5%. Soil samples collected with this method can also be used for other chemical and microbiological analyses.

Additional Index Words: **volumetric analyses, bulk density sampler.**

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PROPER characterization of the soil physical environment is important to defining and interpreting microbiological, chemical, and crop growth processes in the field. Measurement of soil bulk density enables calculation of volumetric soil water content from gravimetric contents, calculation of soil porosity when particle density is known, and expression of soil analysis results on a volumetric basis. Although microbiological and chemical soil analyses are most frequently reported on a gravimetric basis, the conditions are not representative of soil bulk densities that exist in the field at the time of sampling and, in many cases, lead to improper interpretation of experimental results. One reason for the reluctance to report soil analyses on a volumetric basis is the need for specialized equipment and the time involved in obtaining accurate measurements of soil bulk density values at several depths. A rapid and low-cost method is described in this paper to simultaneously take soil bulk density samples at several depth intervals within the upper 300 mm.

MATERIALS AND METHODS

The sampler used was originally designed for taking contamination-free soil cores (JMC "O" contamination tube; Clements Associates, Inc., Newton, IA[3]). The sampler consists of a 348 mm long, 28.7-mm diam metal tube, inside of which is nested an acetate (cellulose acetate butyrate) cylinder 315 mm long and 25.4 mm in diameter (23.8 mm i.d.). Since the cutting tip i.d. is 22.4 mm, this allows a 1.4-mm relief, which reduces friction between the soil and acetate liner during sampling. The sampling tube is designed to be screwed into the end of a standard soil sampling auger handle. We modified the equipment by cutting acetate liners to lengths corresponding to the desired sampling intervals (in our case, 75 mm), replacing the sampler tip securing pin with one that facilitated easier removal, and marking the exterior of the sampler to identify when we had penetrated the soil to a depth of 320 mm beyond the beginning of the acetate liners (Fig. 1). We also fabricated an acetate spacer to account for the differences between the length of the original acetate liner and the sum of the lengths for the sampling depths chosen.

Samples are taken in the same manner normally employed in taking samples with a hand sampler. The sampler tip is pressed vertically into the soil with even pressure. When the sampler tip has penetrated to a depth of 320 mm, it is rotated 90 to 180° and then pulled slowly out of the soil. The sampler body is removed from the handle, and the soil-filled liners are pushed out of the sampler tube from the bottom with a 20-mm diam wooden dowel. A check for compaction can be made before removing sampler from the soil, by removing the handle and inspecting the relative height of soil inside and outside the sampler. A 38-mm diam section of polyvinyl chloride plumbing pipe, cut longitudinally in half, was used as a cradle to hold the soil-filled liners when they were removed from the sampling tube (Fig. 1). The transparent acetate sections are examined for quality of sample. Excess soil is trimmed off flush with the bottom acetate cylinder, and the soil cores are separated at each depth between the acetate cylinders with a spatula or thin-bladed knife. Each soil core is pushed from its acetate liner into a container designated for compositing samples from each depth. Under most conditions of soil sampling, expulsion of cores is easily accomplished because the i.d. of the sampling tip is slightly smaller than the i.d. of the acetate liners.

We collected our composite samples in 0.95-L (1-quart) canning jars, which were capped between samplings to reduce water loss from soil. The previously tared sample jars containing the soil are weighed to determine soil wet weight, and, after thorough mixing, a 50-g subsample is taken from the composite for determination of soil water content. The rest of the composite sample (about 300 g for 75-m depth increment and 10 cores) can be used for other chemical or microbiological analyses. Soil bulk density is calculated by dividing oven dry weight for the composite soil sample by the total volume of soil sampled at each depth. Cross-sectional area of each core is equal to 394 mm^2, where the i.d. of the probe-cutting tip equals 22.4 mm.

We compared results obtained with this sampler, hereafter referred to as a tube sampler, with those obtained with a Uhland sampler (Uhland, 1949) at two different sites. The first site was on a Crete-Butler silty clay loam (fine, montmorillonitic, mesic Pachic Argiustolls-Abruptic Argiaquolls) and had been nontilled for several years. Soil bulk densities were determined using the Uhland sampler at four places, spaced 3 m apart and located between previous crop rows where there was no wheel traffic. Four tube samples were taken in a circle within 100 mm of the center of each Uhland sample at 90° intervals around the circumference. The *t*-test for mean separation was used to evaluate differences between methods.

Test of hypotheses for equal variance has been performed on the 0- to 75-mm, 75- to 150-mm, 150- to 225-mm, and 225- to 300-mm depths. The null hypothesis that variance of the two methods for 0 to 75 mm is equal was rejected

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[3] Mention of companies or commercial products does not imply recommendation or endorsement by the USDA or the Univ. of Nebraska-Lincoln over others not mentioned.

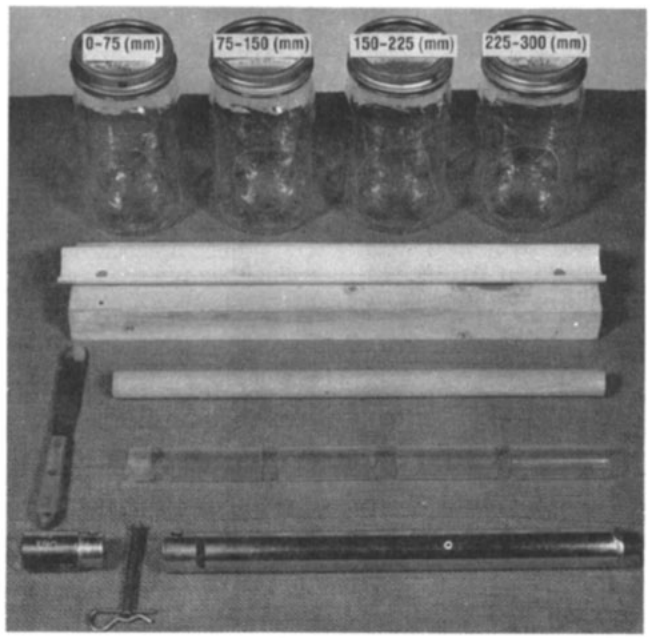

Fig. 1— Equipment used for soil bulk density determinations with the hand tube sampler. From front to rear: Sampling tube with retaining pin and adapter for sampler handle, acetate liners, wooden dowel for removing cores, cradle for cutting cores, and jars for containing composite samples.

($p > F' = 0.043$), and t-test of unequal variance was performed and results showed no significant difference at $\alpha = 0.05$ between the two methods ($p > |T| = 0.30$). The null hypothesis that variance of the two methods for 75- to 150-mm, 150- to 225-mm, and 225- to 300-mm depths is equal was accepted ($p > F' = 0.86$, 0.39, and 0.33, respectively). The t-test of equal variance was performed, and no significant differences were shown between the two methods at $\alpha = 0.05$ with $p > |T| = 0.30$, 0.20, and 0.09 for the 75- to 150-mm, 150- to 225-mm, and 225- to 300-mm depth, respectively. The minimum number of samples needed to obtain a 5% coefficient of variation at the 0.05 probability level was calculated as described by Petersen and Calvin (1965) using the relationship

$$N = t_\alpha^2 S^2 / D^2$$

where

N = number of samples,
t_α = student's t with $(n-1)$ degrees of freedom and α = probability level (0.05) ($n = 4$ for Uhland sampler and $n = 16$ for tube sampler),
S = standard deviation, and
D = given precision desired [0.05 (average bulk density)].

Table 1—Comparison of Uhland and tube method for sampling soil bulk density at four depths on the Crete-Butler silty clay loam.

Sampling depth	Soil bulk density		Minimum number of samples	
	Uhland†	Tube‡	Uhland§	Tube§
mm	Mg m^{-3}			
0-75	1.39 (0.02)¶	1.37 (0.05)	0.6	4.6
75-150	1.47 (0.05)	1.42 (0.04)	3.3	2.2
150-225	1.42 (0.03)	1.40 (0.01)	2.5	0.7
225-300	1.36 (0.04)	1.40 (0.02)	4.2	0.9

† Average of four replications. No significant difference in method means by t-test at $p < 0.05$.
‡ Average of four replications with four observations per replication.
§ Number of samples required to obtain a 5% coefficient of variation at the 0.05 probability level.
¶ Mean and standard deviation (in parentheses).

Comparisions of the two methods were also made at a second site on a Duroc loam (fine-silty, mixed, mesic Pachic Haplustolls) in western Nebraska, where replicated tillage comparisons had been conducted with dryland wheat production for 13 yr at the time of sampling. The tillage treatments were replicated three times. Uhland samples were taken at one location in each plot, whereas tube samples were composites of 10 locations within each tillage replicate. Both sampling techniques required about 30 min to sample soil from four depths of each tillage replicate.

Analysis of variance between methods was made within tillage practices and sampling depths, across tillage practices within depths, and across depths within tillage practices.

RESULTS AND DISCUSSION

As illustrated in Table 1, there were no significant differences in soil bulk density measurements between methods at the Crete-Butler silty clay loam site. Statistical comparisons between methods were made for both the average of four tube samples for each Uhland sample and for one tube sample chosen at random for each site. Precision of measurement was good with both methods, and coefficient of variation ranged from 1 to 5%. Most of this variation, however, was probably associated with inherent variability in the field. The number of samples needed to obtain a 5% coefficient of variation at the 0.05 probability level ranged from one to five for either method. Thus, a minimum of five samples per measurement should be taken with the tube sampler.

Comparisons between methods were also made on different tillage practices at the Duroc loam site. As shown in Table 2, both methods gave similar results that were not significantly different from each other

Table 2—Comparison of Uhland and tube method for sampling soil bulk densities on different tillage practices at four depths on the Duroc loam.

Sampling method	Soil bulk density, Mg m^{-3}				Difference by depth†
	Sod	No tillage	Subtillage	Plow	
		0-75 mm			
Uhland‡	1.01	1.02	1.08	1.18	NS
Tube§	0.92	1.01	1.11	1.19	
		75-150 mm			
Uhland	1.26	1.32	1.36	1.34	*
Tube	1.24	1.28	1.34	1.30	
		150-225 mm			
Uhland	1.33	1.37	1.38	1.37	*
Tube	1.29	1.34	1.35	1.33	
		225-300 mm			
Uhland	1.41	1.37	1.34	1.37	NS
Tube	1.31	1.34	1.35	1.33	
Difference by tillage†	*	NS	NS	NS	

† Statistical significance of difference between methods by F-test within depth or tillage practice. (NS = not significant, * = difference at $p < 0.05$). Tillage-by-method and method-by-depth interactions were not significant at $p < 0.05$).
‡ Averages of three replicates. Coefficients of variation were 1.1 to 8.8% for the Uhland method and 1.3 to 5.9% for the tube method. No significant difference between methods across tillage and sampling depths at $p = 0.05$.
§ Average of 30 replicates.

across tillage treatments and sampling depths. Statistical analysis by depth, however, revealed that soil bulk density values with the tube method were significantly lower than those with the Uhland method at the 75- to 150-mm and 150- to 225-mm sampling depths. Also, bulk density values by the tube method for sod across all depths were significantly lower than those with the Uhland method. Since the Uhland method involves pounding a core into the soil, higher bulk density values with this method may have resulted from compaction during sampling. The relief between the tip diameter and the acetate liners with the tube method reduces or eliminates compaction.

We have used the tube method for sampling soil bulk densities on medium-textured soils at several locations in the United States. It is a simple, reliable method for sampling of soil bulk densities at several intervals to a depth of 300 mm. As with any core technique, its use is limited to soils containing few rocks or gravel at soil water contents below field capacity (Blake, 1965). Observations while sampling with the tube sampler showed frequency of failure to obtain an adequate sample was greatest when soil water conditions were either very dry or wet. The tube method appears to be more accurate because compacted samples are easily detected and discarded. This method is also as precise as the Uhland method with coefficients of variation for field samples averaging less than 5%. This method offers several additional advantages:

1. If soil compaction occurs during sampling, it can be detected before removing the sampler from the soil;
2. A composite of several samples (5–10), which can be used for other analyses, is taken in the same period of time or less than that needed for one sample by other methods; and
3. The equipment used is commercially available at a relatively low cost (< $125).

This method should enable plant, soil, and environmental scientists to measure soil bulk density values accurately. This will enable evaluation of physical, chemical, and microbiological parameters of the soil environment on a volumetric basis.

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